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2. Patent application number *(The Patent Office will fill in this part)*	11 JUN 2003	0313470.7
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Cambridge Consultants Limited Science Park Milton Road Cambridge CB4 0DW	
00361618004 Patents ADP number *(if you know it)*		
If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom	
4. Title of the invention	Handwheel-Operated Device	
5. Name of your agent *(if you have one)*	Keith W Nash & Co	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	90-92 Regent Street Cambridge CB2 1DP	
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Signature Keith W Nash & Co Date 11.06.2003

Keith W Nash & Co

12. Name and daytime telephone number of person to contact in the United Kingdom — David L Roberts - 01223 355477

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C1321.00/C

TITLE: HANDWHEEL-OPERATED DEVICE

Field of the Invention

This invention relates to a handwheel-operated device and to a method of controlling a motor of a handwheel-operated device by sensing rotation of the handwheel and causing the motor to rotate a chuck in dependence upon the rotation of the handwheel.

Background to the Invention

Mechanical devices of the kind having a handwheel connected to a chuck through a gear train, so that rotation of the handwheel causes a corresponding rotation of the chuck are well known. Hand drills and hand whisks are examples of such devices. These handwheel-operated devices are popular because a handwheel affords a high degree of control over the speed of rotation of the chuck. However, the magnitude of the speed and/or torque that can be developed at the chuck is limited by the magnitude of the speed and/or torque applied to the handwheel, which must be provided by the user. Such devices are therefore unsuitable for use over long periods or by users who lack physical strength, or if high levels of both speed and torque are required.

Summary of the Invention

According to a first aspect of the invention there is provided a handwheel-operated device comprising a body, a handwheel causes aand a chuck, the handwheel and the chuck being rotatable relative to the body, the device further comprising a first motor operable to rotate the chuck, first sensor means responsive to rotation of the handwheel and first control means operable in conjunction with the first sensor means to cause the first motor to rotate the chuck in dependence upon an angular displacement and/or angular velocity of the handwheel.

The invention therefore provides a handwheel-operated device that is operable by a user in the same manner as a conventional handwheel-operated device, such as a hand drill or a

hand whisk, but which, for a particular speed and/or torque applied to the handwheel, is capable of developing considerably more speed and/or torque at the chuck than would a conventional handwheel-operated device.

The first control means may be operable to modulate a voltage applied to the first motor, preferably so that the magnitude of the voltage is substantially proportional to the angular velocity of the handwheel.

This type of first control means is relatively straightforward to implement.

Preferably, the first control means is operable to modulate a voltage applied to the first motor such that an angular displacement and/or angular velocity of the handwheel. results in a corresponding angular displacement and/or angular velocity of the chuck. With this type of first control means, the response of the chuck to rotation of the handwheel is much closer to that of a conventional handwheel-operated device, where the handwheel and chuck are mechanically coupled to one another, for example by a gear train, since changes in the loading on (i.e. resistance to rotation of) the chuck will not alter the relationship between handwheel and chuck position and/or speed.

Preferably the first control means is operable to cause the polarity of the applied voltage to be dependent on the sense of rotation of the handwheel so that changing the direction of rotation of the handwheel reverses the polarity of the applied voltage, and hence reverses the direction of rotation of the chuck.

Preferably the first control means is operable to modulate the voltage applied to the first motor in dependence on the angular velocity of the handwheel such that the angular velocity of the chuck is non linearly related to the angular velocity of the handwheel, the ratio of handwheel speed to chuck speed decreasing with increasing handwheel speed. Since an increase in handwheel speed causes a greater than proportionate increase in chuck speed, this type of first control means enables a user to obtain very precise control of the angular displacement of the chuck at low speeds of rotation of the handwheel, yet also to

obtain high angular velocities of the chuck that would otherwise require speeds of rotation of the handwheel that would be difficult or impossible for the user to achieve or sustain.

Precise control of the angular displacement of the chuck is useful where the device is used, for example, as a screwdriver, and a user wishes to align a screwdriving bit in the chuck of the device with a slot in the head of a screw.

The first sensor means may advantageously comprise an angular displacement sensor such as a rotary encoder. Preferably the handwheel is attached to a shaft of the angular displacement sensor.

In a preferred embodiment of the invention, however, a first gear wheel is attached to the shaft of the angular displacement sensor, a second gear wheel is attached to the handwheel, and the first and second gear wheels are engageable with one another either directly or via one or more intermediate gears, so that each revolution of the second gear wheel causes the first gear wheel to rotate through more than 360°, preferably a plurality of revolutions.

In this way, an inexpensive low-resolution angular displacement sensor, which produces, say, eight pulses during one revolution of its shaft, can be used, because each revolution of the handwheel will cause several revolutions of the shaft of the angular displacement sensor, and therefore a multiple of eight pulses during a revolution of the handwheel. Thus, provided that the ratio of the diameters of the first and second gear wheels is sufficiently large. The performance of an expensive high-resolution angular displacement sensor can be obtained using an inexpensive low-resolution encoder.

The device may advantageously further comprise second sensor means operable to determine a torque developed by the first motor, torque feedback means coupled to the handwheel and second control means operable in conjunction with the second sensor means to cause the torque feedback means to oppose the rotation of the handwheel.

In this way a user of the device may be provided with an indication of the torque developed by the first motor, which adds to the user's impression of a mechanical coupling between the handwheel and the chuck.

The second sensor means may advantageously comprise a force sensor and the first motor be mounted in the body of the device such that, in use, a torque developed by the first motor causes a torsional reaction force to be exerted on the force sensor.

The force sensor may advantageously be a piezoelectric crystal.

Alternatively, the second sensor means may advantageously comprise measurement means for measuring one or more parameters related to the torque of the first motor, and computation means operable to derive a torque of the first motor from the one or measured parameters.

Preferably the measurement means is operable to measure a current supplied to the first motor.

The torque feedback means may advantageously comprise a variable brake engageable with the handwheel under the control of the second control means.

The torque feedback means may more advantageously still comprise a second motor on a shaft of which the handwheel is mounted, the second control means being operable to supply current to the second motor so as to oppose the rotation of the handwheel.

In a preferred embodiment of the invention, however, the rotary encoder forms is coupled to the second motor and the first gear wheel is attached to a shaft of the second motor.

The handwheel may advantageously be provided with a handle movable between a folded position and an extended position.

Preferably the device further comprises switch means engageable with the handle, such that the first control means is operable to cause the first motor to rotate the chuck only when the handle is in the extended position.

Alternatively, the device may include a further manual control (for example a trigger switch), manipulable to cause the first motor to rotate the chuck when the handle is in its folded condition.

Preferably the device is a power tool.

In one embodiment of the invention the device is a cordless electric drill.

In another embodiment of the invention the device is an electric food blender.

According to a second aspect of the invention there is provided a method of controlling a motor of a handwheel-operated device, the device having a body, a handwheel, a chuck and a motor, the handwheel being rotatable relative to the body and the motor being operable to rotate the chuck relative to the body, the method comprising sensing rotation of the handwheel and causing the motor to rotate the chuck in dependence upon the angular displacement or angular velocity of the handwheel.

The invention will now be described by way of illustrative example and with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a cordless drill in accordance with the first aspect of the invention;
Figure 2 is a schematic sectional view of the drill of Figure 1;
Figure 3 is a partial schematic sectional view of the drill of Figures 1 and 2 along the line A-A;
Figure 4 is a block diagram of a first control scheme for the drill of Figures 1 to 3;
Figure 5 is block diagram of a second control scheme;

Figure 6 is block diagram of a third control scheme;

Figure 7 is block diagram of a fourth control scheme;

Figure 8 is a graph of amplifier gain and hence angular velocity of the chuck of the drill against angular velocity of the handwheel;

Figure 9 is block diagram of a detail of the fourth control scheme;

Figure 10 is block diagram of a fifth control scheme;

Figure 11 is a sectional view of the handwheel with the handle in a folded position;

Figure 12 is a sectional view of the handwheel with the handle in an extended position;

Figure 13 is a side view of an electric whisk in accordance with the first aspect of the invention; and

Figure 14 is a block diagram of a motor model used in the fifth control scheme.

Detailed Description of Embodiments

The cordless drill 10 of Figure 1 comprises a body 12, a handwheel 14 and a chuck 16. Except for the handwheel, the drill 10 superficially resembles a conventional drill, with a pistol grip 18, trigger switch 20 located in the pistol grip, and forward housing portion 22 located in front of the trigger. The handwheel 14 is attached to the portion 22. A rechargeable battery 24 is removably attached to the base of the body.

Turning to Figure 2, from which the battery 24 has been omitted for the purpose of clarity, the body 12 contains a first motor 26, a first rotary encoder 28, a gearbox 30, a second motor 32, a second rotary encoder (not shown), and first and second gear wheels 34 and 36, respectively. The first rotary encoder 28 is made up of a multipole magnet and three Hall effect detectors and is attached to a first end of the spindle of the first motor 26. The gearbox 30 is coupled to a second end of the spindle of the first motor 26 and to the chuck 16.

The first gear wheel 34 is attached to the spindle of the second motor 32. The second gear wheel 36 is attached to the handwheel 14 and to a spindle on which the handwheel rotates. The second motor 32 and the spindle on which the handwheel rotates are so located that the first and second gear wheels engage with one another, such that when the handwheel is

rotated, the second motor is driven. The second gear wheel has a diameter that is between three and four times the diameter of the first wheel. For each revolution of the handwheel, therefore, the first gear wheel makes between three and four rotations, which increases the effective resolution of the second rotary encoder by between three and four times.

The handwheel 36 has a folding handle 38, which is shown in an extended position in Figures 1 and 2. The handle can be moved into a folded position, and is engageable with a microswitch (not shown) in the folded position, which microswitch disconnects the second rotary encoder from the first control means.

The first motor and gearbox are secured in the body by resilient mounts, which allow a small amount of torsional movement of the motor and gearbox relative to the body. The gearbox is formed with a radially outwardly projecting member 40. A piezoelectric crystal (not shown) is located to either side of the member 40 such that if torsional movement of the motor and gearbox relative to the body occurs, a force is exerted on one or other piezoelectric crystal.

The arrangement of the member 40 and the piezoelectric crystals is shown more clearly in Figure 3, in which the piezoelectric crystals are denoted by reference numerals 42 and 44. Figure 3 is a sectional view along the line A-A of Figure 2.

Figure 4 shows a first control scheme in which the speed of rotation of the handwheel is measured and a pulse width modulated (PWM) voltage of magnitude proportional to the speed of rotation of the handwheel is applied to the first motor. As the handwheel is rotated, pulses are generated by the second rotary encoder. A first clock 46 determines the frequency of the pulses and generates a signal representative of the speed of rotation of the handwheel. The signal representative of the speed of rotation of the handwheel is used to generate a PWM voltage which drives a first field effect transistor (FET) h-bridge 48. The first motor 26 is connected across the first h-bridge 48.

Figure 5 shows a second control scheme in which the speed of rotation of the handwheel is measured and a feedback loop is used to ensure that the speed of rotation of the chuck is proportional to that of the handwheel. With only minor changes it would be possible instead to measure the angular displacement of the handwheel from a reference orientation and use the feedback loop to ensure that the angular displacement of the chuck from a reference orientation is proportional to that of the handwheel.

The first clock 46 determines the frequency of the pulses generated by the second rotary encoder to generate a signal representative of the speed of rotation of the handwheel. At the same time a second clock 52 determines the frequency of pulses generated by the first rotary encoder to generate a signal representative of the speed of rotation of the chuck. The signals representative of the speeds of rotation of the chuck and handwheel are compared by a microprocessor 50 to generate a speed error signal. The microprocessor generates a PWM voltage to drive the first h-bridge 48 and control the speed of rotation of the first motor so as to reduce the magnitude of the error signal.

Figure 6 shows the control scheme of Figure 5 modified by a further feedback loop, which enables a retarding force to be applied to the handwheel, which retarding force is approximately proportional to the torque developed by the first motor 26. The control scheme shown in Figure 6 is as described in relation to Figure 5. However, a voltage developed by the piezoelectric crystals 42 and 44, which is subjected to a compressive force due to the reaction torque on the motor, is applied to a microprocessor 54. The microprocessor 54 generates a PWM voltage to drive a second FET h-bridge (not shown). The second motor 32 is connected across the second h-bridge and the PWM voltage generated by the microprocessor 54 causes the second motor to generate a torque which opposes the rotation of the handwheel.

Figure 7 shows a control scheme similar to that shown in Figure 6, but with a further feedback loop to ensure that the torque generated by the second motor to oppose the rotation of the handwheel is proportional to the torque generated by the first motor.

In the control scheme of Figure 7 the handwheel 14 is rotated and causes the spindle of the second motor 32 to rotate and the second rotary encoder 56 to generate pulses. The first clock 46 measures the frequency of the pulses from the second rotary encoder and generates a signal representative of the speed of rotation of the handwheel. An amplifier 58 applies a gain to the signal representative of the speed of rotation of the handwheel to generate an amplified speed signal. The gain of the amplifier increases with the magnitude of signal representative of the speed of rotation of the handwheel. Figure 8 shows the gain characteristic 63 of the amplifier 58 with gain plotted against magnitude of the signal representative of the speed of rotation of the handwheel. Gain is plotted on the y-axis 65 and magnitude of the handwheel speed signal on the x-axis 67. The gain of the amplifier therefore determines the ratio of the speeds of rotation of the chuck and the handwheel. The amplified speed signal is applied to a first proportional plus integral (PI) controller 60.

The spindle of the first motor 26 rotates and causes the first rotary encoder 28 to generate pulses. A third clock 62 measures the frequency of the pulses and generates a signal representative of the speed of rotation of the first motor. The signal representative of the speed of rotation of the first motor is applied to the PI controller 60. A current sensor (not shown) measures the current flowing through the first motor and generates a signal representative of the current flowing through the first motor. The current sensor transmits the signal to the first PI controller 60. The first PI controller 60 generates a PWM voltage to drive the first h-bridge 48 to cause the spindle of the first motor to rotate at the speed determined by the gain of the first amplifier 58, whilst ensuring that the current flowing through the motor remains below a safe limit. The current limiting operation of the first PI controller 60 is explained in more detail below in relation to Figure 9. The battery 24, which was omitted from Figures 4 to 6 for the purpose of clarity, is shown in Figure 7 connected to the first h-bridge 48 and the second h-bridge 64 across which the second motor 32 is connected.

The piezoelectric crystal 42 and 44 generates a voltage proportional to the torque developed by the first motor 26. An attenuator 66 attenuates the voltage generated by the crystal 42 to generate a signal representative of a fraction of the torque developed by the

first motor 26. The attenuated torque signal is applied to a second PI controller. A current sensor 70 generates a signal representative of the current flowing through the second motor 32 from the second h-bridge 64. A second microprocessor 72 generates a signal representative of an estimated torque developed by the second motor 32 and applies this signal to a second PI controller 68. The second PI controller generates a PWM voltage to drive the second h-bridge 64 so as to cause the second motor 32 to generate a torque equal to the fraction of the torque generated by the first motor 26.

Turning to Figure 9, the current limiting operation of the first PI controller 60 is shown. The PI controller 60 in fact comprises an outer, relatively slow PI controller 74, a current limiter 76 and an inner, relatively fast PI controller 78. In Figure 9 the first h-bridge 48, first motor 26, first rotary encoder 28, second clock 62 and current sensor of Figure 7 are represented by the functional block 80.

The outer PI controller 74 receives signals representative of a demanded motor speed from the amplifier 58 and signals representative of the actual motor speed from the first rotary encoder 28 and third clock 62 and generates a signal representative of a demanded current. The demanded current is that which will cause the actual motor speed to approach the demanded motor speed. The signal representative of the demanded current is transmitted to the current limiter 76, which either transmits the signal representative of the demanded current to the inner PI controller 78, or if the signal representative of the demanded current exceeds a threshold value, transmits a signal representative of a limited demanded current to the inner PI controller 78.

The inner PI controller receives the signal representative of the demanded current (whether or not limited) and a signal representative of the actual motor current from the current sensor. The inner PI controller generates a PWM voltage to drive the first h-bridge so as to cause the actual current flowing through the motor to approach the demanded current.

Figure 10 shows a variation of the control scheme shown in Figure 7, in which a torque developed by the first motor is calculated from parameters of the first motor related to

torque, rather than measured directly. The operation of the first motor 26, first rotary encoder 28, second motor 32, second rotary encoder 56, first clock 46, amplifier 58, first PI controller 60, first h-bridge 48, attenuator 66, second PI controller 68, current sensor 70, microprocessor 72 and third clock 62 is as previously described in relation to Figure 7. However, the first PI controller 60 receives the signals representative of the first motor current from voltage and current sensors 82 operable to generate signals representative of the voltage developed across, and current flowing in, the first motor 26.

The voltage and current sensors 82 transmit signals representative of the voltage developed across, and current flowing in, the first motor 26 to a second microprocessor 84. The second microprocessor also receives pulses from the first rotary encoder 28 and generates a signal representative of the load torque developed by the first motor 26, which is transmitted to the attenuator 66. The second microprocessor 84 implements a model of the motor, which is explained in greater detail below with reference to Figure 14. The attenuated torque signal is transmitted to the second PI controller 68 to cause the second motor 32 to generate a torque proportional to the load torque generated by the first motor, which torque opposes the rotation of the handwheel 14, as previously described.

Turning to Figure 14, this shows the model implemented by the second microprocessor 84. In the following description it is to be assumed that signals representative of a particular variable are signals representative of the Laplace transform of that variable. The second microprocessor receives a signal representative of the voltage applied to the first motor 26, and the current through it and a signal representative of the angular displacement of the rotor of the first motor from a reference orientation. From previous angular displacement signals the second microprocessor determines the actual speed of rotation of the rotor of the first motor. Using the model an estimate of the motor current and speed may be made. The estimated speed generates a signal representative of the back emf generated by the first motor. The back emf signal is substracted from the motor voltage signal to generate a signal representative of the estimated voltage across the windings of the first motor. The second microprocessor uses the estimated windings voltage signal to generate a signal representative motor current and of the total electrical torque generated by the first motor

26. The second microprocessor also generates a signal representative of a predicted load torque generated by the first motor by comparing the actual current and speed against the estimates and subtracts the signal representative of the predicted load torque from the signal representative of the total electrical torque to generate a signal representative of the accelerating torque developed by the first motor. The second microprocessor generates a signal representative of the estimated speed of rotation of the rotor of the first motor from the accelerating torque signal, from which the back emf signal referred to earlier is generated.

The second microprocessor generates from the estimated rotor speed signal a signal representative of the estimated angular displacement of the rotor from the reference orientation and compares the estimated angular displacement signal with a signal representative of the actual angular displacement of the rotor generated by the first rotary encoder 28. The second microprocessor adjusts the predicted load torque signal to reduce the difference between the actual and estimated angular displacement signals and the difference between the actual and estimated motor current.

The variables shown in the model of Figure 14 are as follows:

$V_{drive}(s)$	-	Laplace transform of the voltage applied to the first motor 26;
K_T	-	torque constant of the first motor;
R	-	armature resistance of the first motor;
L	-	armature inductance of the first motor;
s	-	the Laplace variable;
$T_{elec}(s)$	-	Laplace transform of the total electrical torque of the first motor;
$T_{load}(s)$	-	Laplace transform of the load torque of the first motor;
$T_{accel}(s)$	-	Laplace transform of the accelerating torque of the first motor;
b	-	friction coefficient of the first motor and gearbox;
J	-	inertia of the rotor of the first motor and gearbox;
$\theta(s)$	-	Laplace transform of the estimated angular displacement of the rotor of the first motor;

K_ϕ - electric constant of the first motor; and

V_{bemf} - Laplace transform of the estimated back emf of the first motor.

Returning to Figures 11 and 12, the handwheel assembly of the drill of Figures 1 and 2 comprises the handwheel 14, folding handle 38, spindle 86 to which the handwheel is attached, circular thrust plate 88 through which the spindle 86 passes, and microswitch 90. The folding handle 38 is pivotally attached to the handwheel 14 and is formed with a cam 92. In the folded position (as shown in Figure 11) the cam does not engage with the thrust plate 88, which is biased towards the handwheel 14 by the microswitch. In the extended position, however, (as shown in Figure 12) the cam engages with the thrust plate 88, which causes the microswitch to be depressed, closing the microswitch. The second rotary encoder 56 is connected to the first clock 46 by the microswitch such that the handwheel is operable to control the rotation of the chuck only when the handle 38 is in the extended position and the microswitch closed. When the handle 38 is in the folded position (and therefore inoperable to control the rotation of the chuck, the rotation of the chuck may be controlled by the trigger switch 20, in the manner known from conventional cordless drills.

Figure 13 shows a hand whisk 94 in accordance with the first aspect of the invention. It will be appreciated that the electric hand whisk has two chucks (not shown in Figure 13), one for each whisking element 96 and 98. The hand whisk 94 has a handwheel and a handle 102. In this embodiment of the invention the handle 102 is not foldable, since the whisk can be disabled simply by unplugging it from the mains electricity outlet to which it is connected.

It will be apparent that the foregoing description relates only to six embodiments of the invention, and that the invention encompasses other embodiments as defined by the foregoing statements of the invention.

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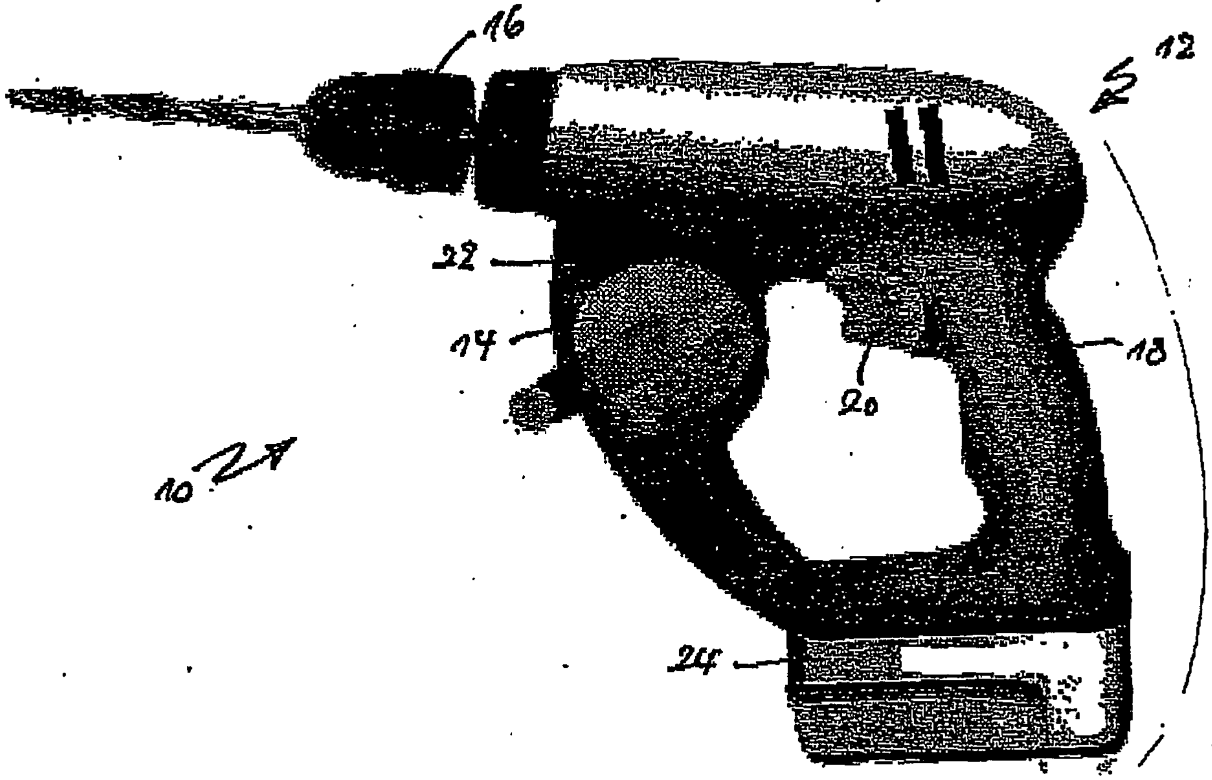

Fig. 1.

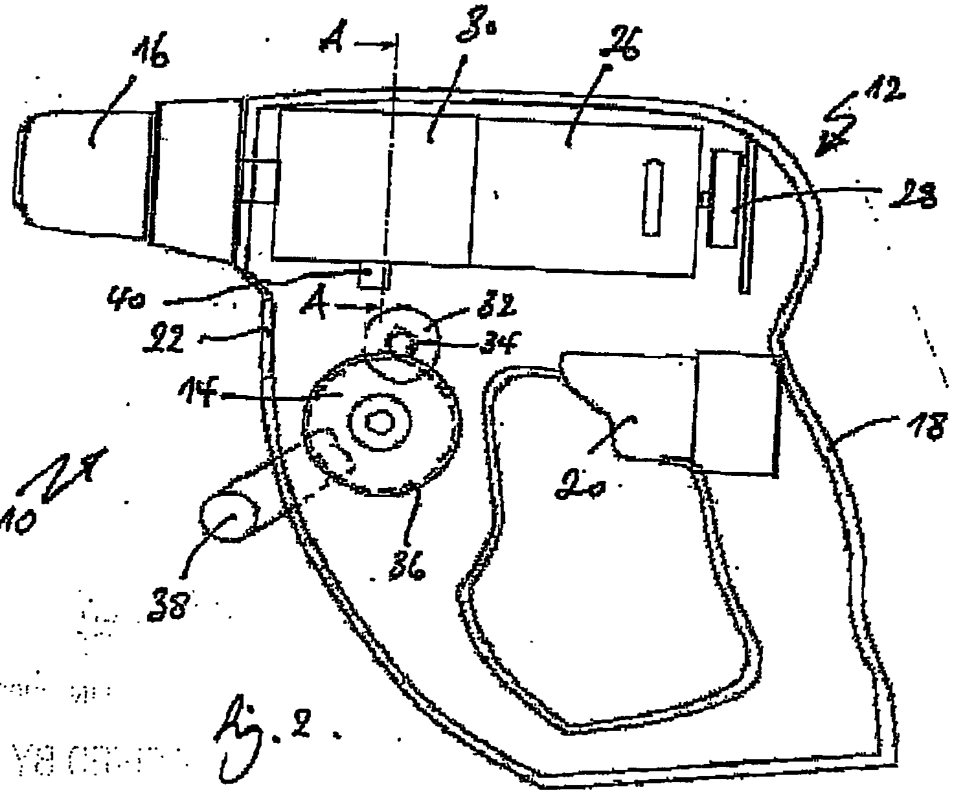

Fig. 2.

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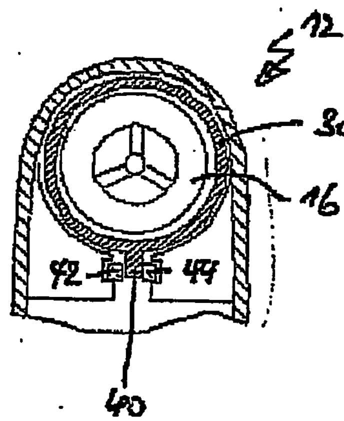

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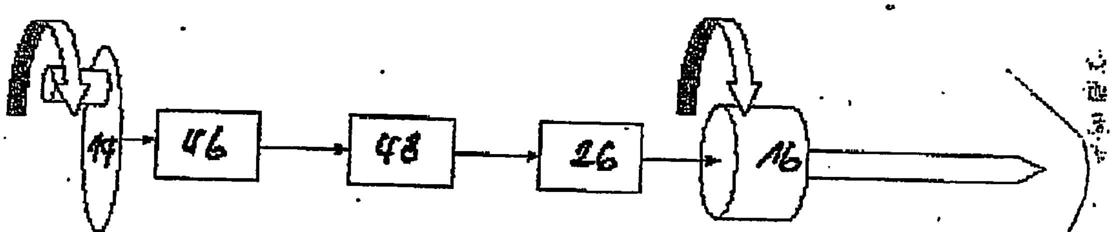

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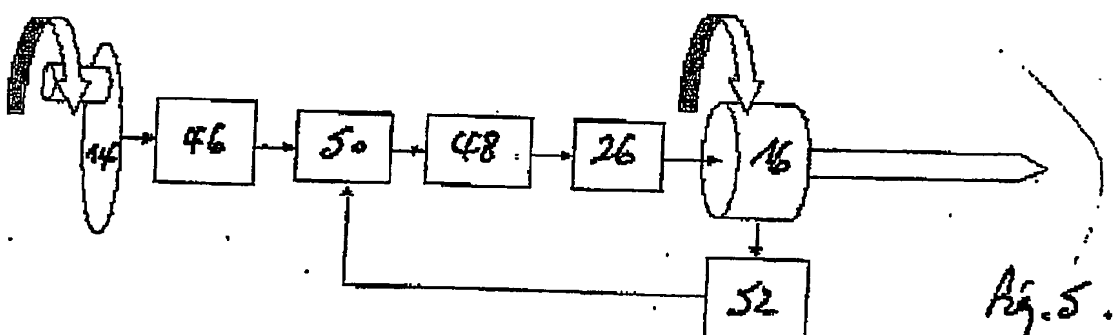

Fig. 5.

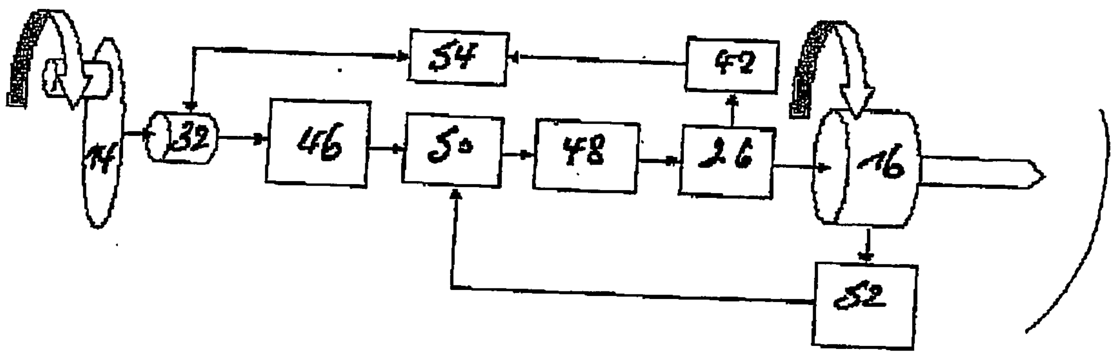
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Fig. 6.

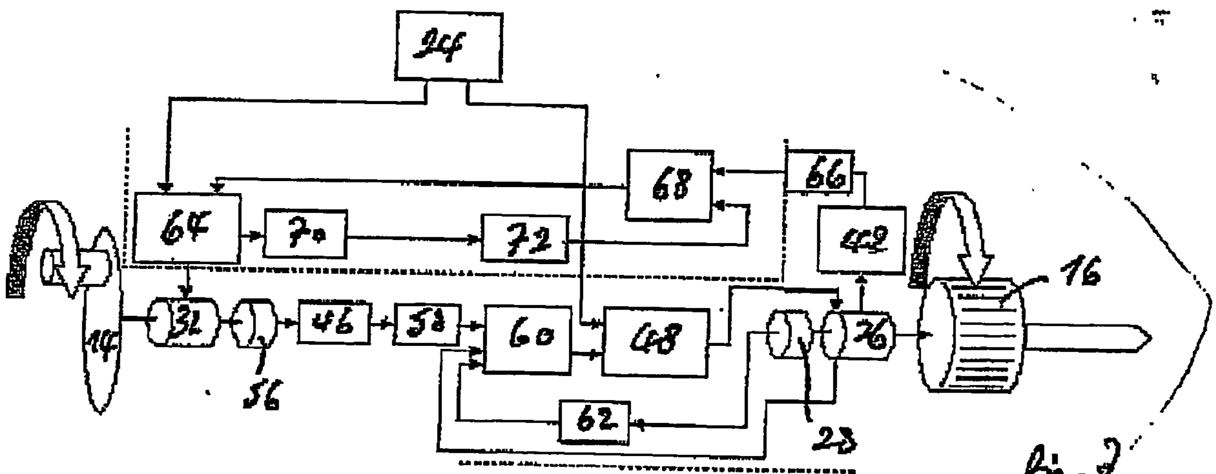
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Fig. 7.

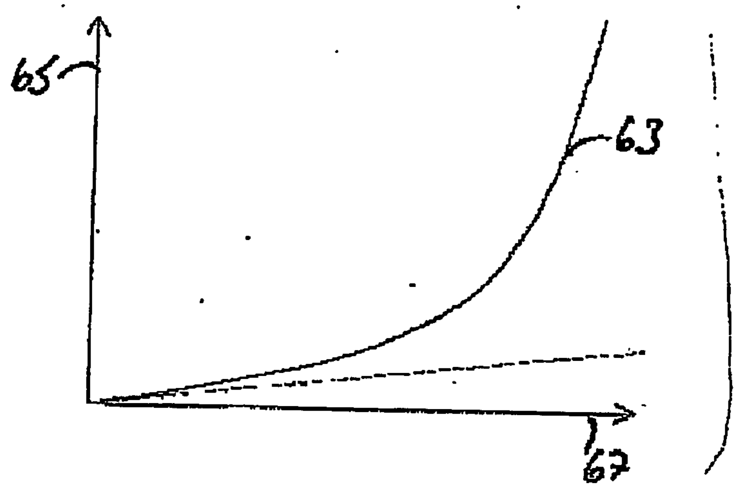

Fig. 8.

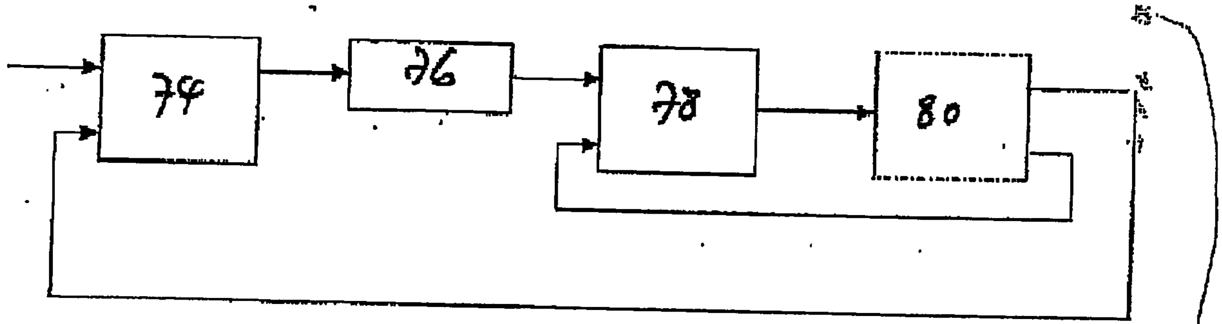

Fig. 9.

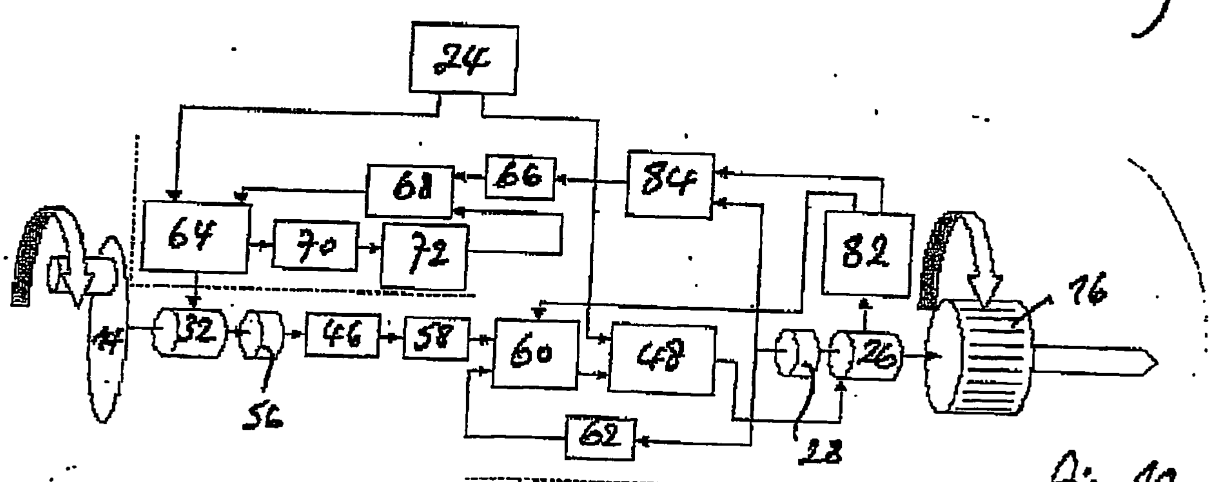

Fig. 10.

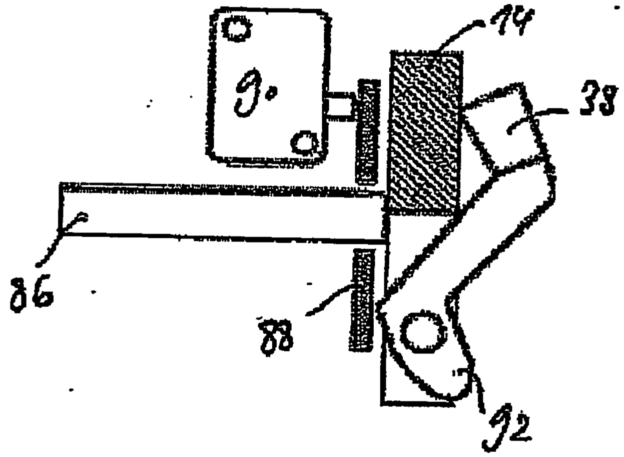

Fig. 11.

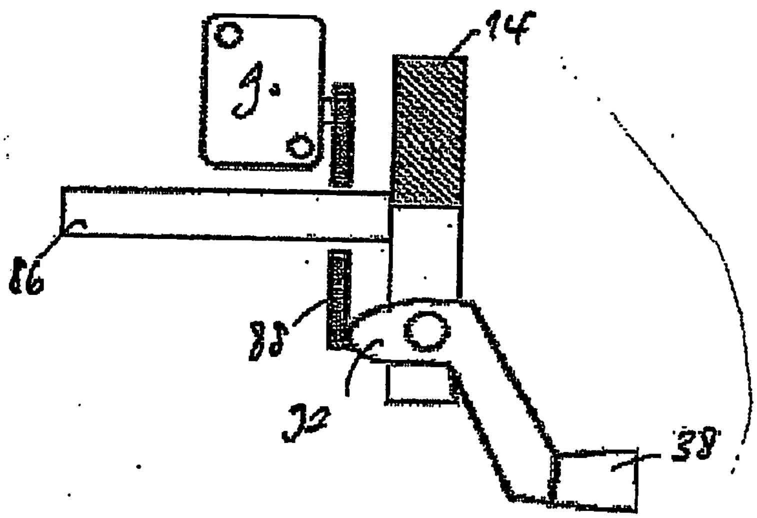

Fig. 12.

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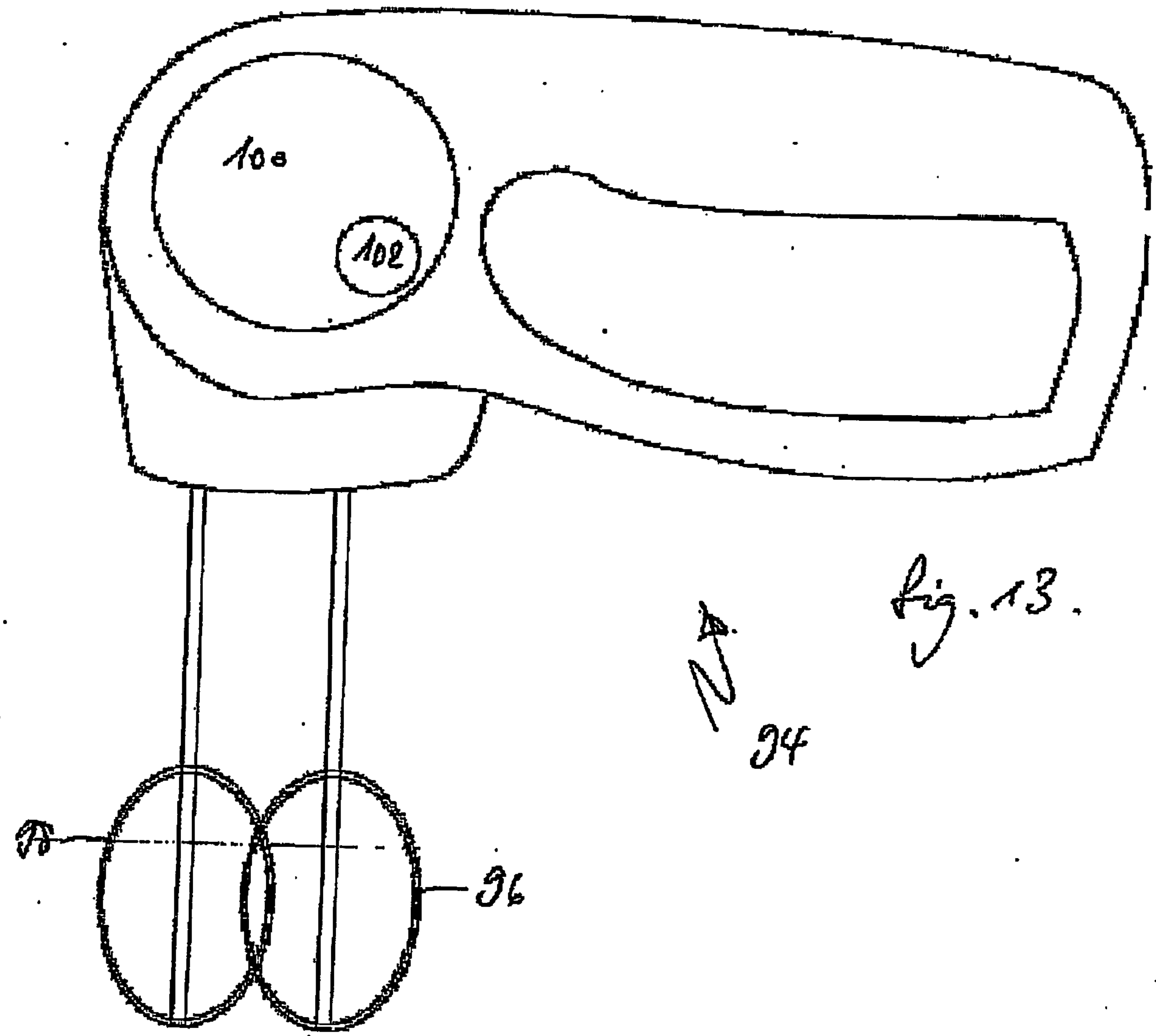

fig. 13.

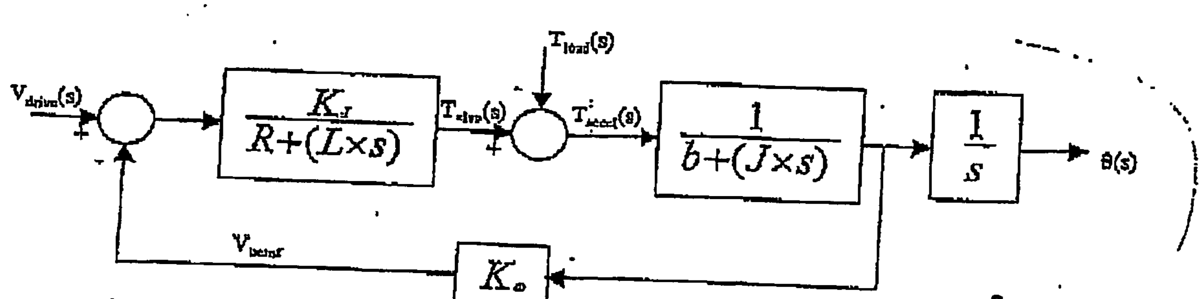

fig. 14.